AD-A050 767 NAVAL RESEARCH LAB WASHINGTON D C F/G 8/8
WAVE MEASUREMENT SYSTEMS APPLICABLE TO GREAT LAKES VESSELS AND --ETC(U)
FEB 78 D L HAMMOND MIPR-Z-70099-4-65879

UNCLASSIFIED USCG-D-4-78 NL

| OF |

AD
A050767

END
DATE
FILMED
4-78
DDC

Report No. CG-D-4-78

11

B.C.

WAVE MEASUREMENT SYSTEMS APPLICABLE TO GREAT LAKE VESSELS AND SPECTRA

FEBRUARY 1978
FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
United States Coast Guard
Office of Research and Development
Washington, D.C. 20590

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
USCG-D-4-78		

4. Title and Subtitle	5. Report Date
WAVE MEASUREMENT SYSTEMS APPLICABLE TO GREAT LAKES VESSELS AND SPECTRA.	Feb[redacted]78
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Donald L. Hammond	37 p.
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
U. S. Naval Research Laboratory Washington, D. C. 20375	3306.02.02.1
	11. Contract or Grant No.
	MIPR-Z -70099-65879
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Final Rep[redacted]t. NOV 76 - [redacted]FEB [redacted]78
Commandant (G-DSA) U. S. Coast Guard Headquarters Washington, D. C. 20590	14. Sponsoring Agency Code G-DSA-1/TP44

15. Supplementary Notes

The U. S. Coast Guard Office of Research and Development's technical representative for the work perform herein was LT M. D. NOLL.

16. Abstract

A shipborne wave measurement system for use on a Great Lake's ore Carrier is proposed. The recommended system uses a modified marine radar to image the water wave pattern in a one mile radius of the vessel. The wave heights are measured using a radar or laser ranging system looking down at the waves from the vessel's deck.

17. Key Words	18. Distribution Statement
Water waves Significant Wave Height Wave Spectra	Document is available to the U. S. public through the National Technical Information Service, Springfield, VA. 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	23 + Fig1-10	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

A 252950

TABLE OF CONTENTS

WAVE MEASUREMENT SYSTEMS APPLICABLE TO GREAT LAKES VESSELS AND SPECTRA

1.0 INTRODUCTION

The purpose of this report is to recommend to the U.S. Coast Guard a shipborne surface water wave measurement system that records the waves while the ship is underway in such a manner that the two-dimensional wave spectrum is obtained.

The U.S. Coast Guard has the responsibility to set the longitudinal strength design standards for commercial vessels. At present, there is a need to set the standard for the longitudinal strength of vessels over 230 meters in length that operate solely on the Great Lakes. To obtain operational data to help establish a longitudinal strength standard, several Great Lakes' vessels have been outfitted with instruments to record wave induced stresses, both wave bending and springing. To complement the above measurements, a shipborne wave measurement system is needed on one or more of these instrumented vessels so that the relation between the water waves encountered and the stresses in the ships' structure can be so determined.

1.1 SUMMARY

At present, there is no operational shipborne wave measurement system that records directional wave spectra while the vessel is in motion. However, there are two on-going research programs that measure water waves with commercial radar systems which can be used in a way described in the body of this report, such that the principal components of the directional wave spectrum can be obtained.

One of the research programs currently active at the Coastal Engineering Research Center (CERC) at Fort Belvoir, Virginia uses a Raytheon Marine Pathfinder Radar Model 1020 to produce images of water waves. This type of marine radar system is used as a navigation aid on the very vessels that are being considered as platforms for the wave measurements. The radar system requires a small number of modifications to permit it to record the wave pattern in a one mile area around the vessel. The wave pattern images have a resolution of less than eighteen meters, and can be recorded by a semi-automatic camera system that was first developed by the U.S. Coast Guard, Research and Development Center at Groton, Connecticut.

Another research program is the design and development of surface effects ships being conducted at the U.S. Naval Air Test Center, Patuxent River, Maryland. In this program, a Collins Radio Co. radar altimeter model ALT-50 is used to measure the distance from the bow of the ship to the water surface. This radar altimeter is able to record the wave height of the water waves near the ship.

This report recommends the following steps be taken for the measurement of the directional wave spectra:

(1) Replace the present marine radar on the m/v Stewart J. Cort with a Raytheon Model 1020

Radar, with the modifications and additional data recording features as discussed in this report.

(2) A Collins Radio Company Model ALT-50 or a laser ranging system also be added mounted on the deck to record the wave heights in the vicinity of the vessel.

(3) A reasonable period of time be allocated to perfect the data reduction process and analysis of results.

Experience at NRL in the measurement of water waves indicates that these radar systems are the prime candidates for this task. However, the specific data reduction method to be employed requires further study.

The estimated costs of the above recommendations are: the installation of a marine radar system for $15,000, the construction of the automatic camera recorder $5,000, the equipment to measure the principal directional wave components for $2,000, the purchase of a Collins Radio Co. radar altimeter for $1,500 or a laser wave height system $25,000, the installation and data recording system $10,000, the purchase of two half meter diameter parabolic antennas $500, and a six-month data analysis study $25,000.

2.0 WAVE MEASUREMENT SYSTEMS

There are five general types of water wave measurement systems. They are: (1) an underwater pressure sensitive transducer that senses the changes in the water level above it, (2) a wave staff that is immersed in the water that electrically measures the movement of the surface vertically along the staff, (3) a floating buoy that uses a vertical accelerometer, some buoys also have pitch and roll sensors, to record the movement of the surface, (4) a range measuring system located above the water surface that uses either radar or laser pulses to measure the surface level changes and (5) an image of the surface wave pattern over an area using photography or imaging radar.

There does not exist now a shipborne wave measurement system that records wave data for the generation of encounter wave spectra while a vessel is underway. The Tucker Meter,[1] which has been used on-board weather ships since 1953, operates by sensing the water pressure changes above two underwater openings in the sides of the vessel's hull and must be operated along with two corresponding vertical accelerometers. These measurements permit the calculation of the variations of the surface level of the water. However, reliable data can only be obtained when the vessel is stationary [2]. Even under the best of conditions, the Tucker meter cannot yield directional wave spectra.

The available techniques for measuring waves from a moving ship is very restricted. The fixed mounted systems such as underwater pressure transducers and wave staffs are clearly not suitable. The Tucker Meter has been used as a shipborne wave sensor producing one-dimensional spectra, but as was mentioned earlier, only gives good results when the vessel is not underway. Photography is eliminated as a

technique to record wave patterns because a camera cannot be mounted on the ship to give large area coverage and the camera cannot operate at night or under low visibility conditions. This narrows the choice to looking for a radar to image the wave pattern and/or a radar to measure the significant wave height. The systems should be commercially available and require little modification to operate as wave sensors.

The U.S. Army Coastal Engineering Research Center (CERC) has successfully used a Marine Radar System mounted in a trailer to record the images of waves near the Coast [3]. The system is effective out to ranges of about one mile with a resolution of about twenty meters. Most ships are normally equipped with one or more such high resolution radars as an aid to navigation and to avoid collisions with other ships. Figure 1 is a photograph of the wave image as recorded by CERC from the beach.

An additional sensor is needed since the high resolution imaging radar does not provide wave heights. A Collins Radio Co. radar altimeter is used by the Surface Effects Ship Research Center at the Naval Air Test Center, Patuxent River, Maryland to measure the height above the water of a ship's bow. This radar can be used in the Great Lakes Study to measure the water wave heights from a vessel when it is mounted high above the water and pointed out to the side of the ship. A laser ranging system can also provide SWH information from the vessel's deck. The laser has better resolution both in the vertical and horizontal directions, but it costs considerably more money.

2.1 THE DIRECTIONAL SPECTRA

The wavy surface of the water can be described as the combination of many directional sinusoidal components. Each wave component is characterized by a crest to crest

wavelength, an amplitude and direction. The combination of many such components of wavelength spanning the spectrum from centimeters to hundreds of meters, amplitudes that range from centimeters to meters and directions around a complete circle make up the surface waves of the water. These amplitudes each associated with a particular wavelength and direction constitute the directional spectrum of the wavy surface.

The calculation of the direction height spectrum requires the measurement of the surface elevations as a function of position. This is very difficult to do. In fact, there is no sensor available today to perform this function.

The sea photo analysis technique comes the closest. This technique was described by D. Stilwell in 1969 [4,5]. Photos are taken of the ambient light reflected by the wavy surface. The variation in the intensity of the reflected light is proportional to the local surface slope oriented toward the camera. The undulations of the light and dark areas correspond to the variations in the surface slope.

The photo negatives are placed in a laser optical processor to produce the two-dimensional Fourier transform of the wave image. Figure 2 shows a schematic of the optical bench. The location of a bright spot in the Fourier transform plane identifies a corresponding spatial frequency and its direction. Figure 3 illustrates that a spatial frequency of wavelength λ_s in the scene image will bend the laser light such that it forms two spots X centimeters from the center of the Fourier transform plane. The spatial frequency is proportional to the distance the spot is from the image center and the direction is the angle between a line joining the spot with the center and another line of reference through the center.

The water wavelengths that are imaged depend on the field of view of the camera and the granularity of the film. The camera is generally mounted in an airplane and looks down at the surface at a 45 degree angle. The water waves imaged from an altitude of about 5000 feet (1524 meters) include wavelengths from about one meter to fifty meters.

2.2 RADAR IMAGE OF THE WATER WAVES

A photo image of the waves cannot be taken from the ship because of the limited field of view, the fact that the photograph depends on having clear day light for illumination and the water surface is often not visible due to fog. A radar image of the waves can be taken day or night and in fog or rain. The marine radar that is normally used by the ship's crew as an aid to navigation and collision avoidance can be used to image the water waves within a mile of the ship. These radar images can be processed in the same way as the photographs in the sea photo analysis technique. The radar does image wave components with wavelengths from about 10 meters to 500 meters.

The photo of the radar image taken by CERC in Figure 1 was processed by Roger Pilon of the Naval Research Laboratory to give the two-dimensional spectrum shown in Figure 4. A mask was placed on the photo to select just part of the radar image as shown in Figure 5. The bright cross in the frequency image is due to the mask. The bright spots in the frequency image are due to the dominant waves in the radar image. They correspond to water waves with a length of about 65 meters.

2.3 MARINE RADAR SYSTEM DESCRIPTION[6]

The Marine Radar presently used on the m/v Stewart J. Cort is an older Raytheon model that does not have the receiver bandwidth or receiver gain control needed to

optimize it as a wave imager. The radar system that has shown it can image water waves[3] by CERC is Raytheon's Marine Pathfinder Radar model 1020/9XR. This radar can be used for its regular navigation functions as well as an imager of water waves.

The radar consists of three main parts; namely, the antenna with its pedestal, the indicator, and the modulator transmitter receiver (MTR)[(6)]. The model recommended has a ten-inch (25 cm) PPI scope display, 20 kw peak transmitter power, a twelve-foot (3.66 m) antenna array and operates at 9375 MHz carrier frequency. The specifications are shown in Table 1.

TABLE 1

PARAMETER	DESCRIPTION		
Range			
Minimum	20 yds (18.3m) on 1/2 mile (914m) range		
Maximum	48 nm (88 Km)		
Resolution (Short Pulse)	20 yds (18.3m) on objects of the same area on the same bearing		
Transmitter			
Operational Frequency	9375 ± 30 MHz (9345 - 9405)		
Peak Power Output	20 kw nominal		
Nominal Pulse Width & PRF			
Range	.5, 1.5, 3	6, 12	24, 48
	.05 msec*	.5 msec	1 msec
	* .5 msec with power boost enabled on 1.5 or 3 mile range		
PRF	3600 PPS (4000 PPS Nom)	1800 PPS (2000 PPS Nom)	900 PPS (1000 PPS Nom)
Receiver			
Intermediate Frequency	45 MHz		
IF Amplifier Bandwidth	15 MHz (0.5 msec PW)		
Video Amplifier Bandwidth	13.5 MHz		
Noise Figure	11 db overall		
Indicator			
Display	10 inch (25 cm) diameter CRT		
Range Resolution	1% or 20 yds (18.3m)		
Antenna			
Type	End-fed Slotted Array		

TABLE 1 (continued)

PARAMETER	DESCRIPTION			
Polarization	Horizontal			
	9-foot (2.75 m) antenna			
Horizontal Beam Width	0.9° at 3 db points			
Vertical Beam Width	23° at 3 db points			
Gain	30 db			
Rotation Speed	33 RPM			
Power Requirements	Supply Voltage	Nominal Current		Fuse Required
	115 v, 1 phase 50-60 Hz	4.4A		10 AFNM
Dimensions and Weight	Height (cm)	Width	Depth	Weight (kg)
MTR	(61)	(56)	(30)	(22.5)
Indicator	(61)	(56)	(38)	(25)
9-foot Antenna	(56)	(275) (swing circle)	(38)	(71.5)
System Environment	Antenna	MTR		Indicator
Ambient Temperature Range	-25° to +65°C,	-15° to +55°C,		-15° to +55°C
Relative Humidity (at 55°C)	95% all units			
Shock (all planes)	20G	15G		15G
Vibration	1G at 5 - 50 Hz all units			
Water proofing	24 hours at Drip-proof 1 inch/hour or 1 hour at 5 inches/hour			
Rated Wind Load				
Operating	100 knots			
Survival	150 knots			

2.3.1 RANGE RESOLUTION

The resolution in range measurement is given by Raytheon as 20 yards (18 meters). The limit to range resolution due to the 13 megahertz video amplifier bandwidth is about 3.75 meters. The limit in resolution due to the pulse width of 50 nanoseconds is about 7.5 meters. The specified resolution of 18 meters is therefore a conservative value. This is the case when the ten-inch (25 cm) PPI scope is used. The larger twelve (30 cm) and sixteen inch (41 cm) PPI scopes use digital processing with samples taken at 15 yard (13.5 meter) intervals so that the range resolution can be no better than 15 yards (13.5 m). Therefore, the best range resolution can be realized by using the ten-inch (25 cm) PPI.

The width of the short pulse can be adjusted by observing on a test scope the waveform at the junction of CR-9 and R-39 on the Pulse Driver Printed Circuit Board. The pulse width is varied by adjustment with a screw driver of potentiometer R-28 on the pulse Driver Printed Circuit Board. The test point (CR-9 and R-39) will have a voltage with a base line at -400 volts that rises to +120 volts and returns to -400 volts. A width of 65 ns measured at the zero volt level will result in a 50 ns radar pulse. The shortest possible pulse is about 42 ns and is limited by the modulator circuits that follow and the transmitter magnetron. The short pulse, as set at the factory, is already near the limit of the transmitter such that no further reduction in pulse width is possible.

2.3.2 RECEIVER GAIN CONTROL

The radar image shown in Figure 1 shows intense returns at the near ranges at the center of the image and very weak returns at the edge of the image. These characteristics of the radar returns make a poor image for data processing.

Therefore, it is necessary to produce an image with a more uniform response with distance.

The Model 1020 Mariners Pathfinder Radar has a sensitivity time control (STC) that allows the operator limited control of the characteristic of the intermediate amplifier gain as a function of target range. This feature is intended to give returns from distant targets more amplification than nearby target returns.

The average intensity of the radar signals backscattered from the surface of the water decrease as the seventh power of the range. This result is due to a combination of the following range dependent factors. The spherical spreading of the radar energy shows a decrease in return intensity as the fourth power of the range. The normalized cross section of the backscattered energy decreases as the fourth power of the range at the very small depression angles involved in this configuration. The geometric area illuminated increases in direct proportion with the range. The resultant product of these three factors is a function that decreases as the seventh power of the range.

This means that for the range interval from a tenth of a mile to one mile the surface scattered returns will decrease by seventy decibels. A compensating gain change in the radar amplifiers would give the same average brightness for the surface returns over this range interval. The radar amplifier's gain can only be varied by fifty decibels. Therefore, the best that can be done is to have a gain versus range waveform that changes the gain by the full fifty decibel control interval for the range interval from a tenth of a mile to about five tenths of a mile and remains constant the rest of the sweep.

2.3.3 RECEIVER TURN ON DELAY

The time delay between the transmitter pulse and receiver turn on is varied with adjustment of potentiometer R-50 on the pulse driver printed circuit board. This delay can be set anywhere from 0.3 to 1.8 microseconds. If this is set for 1.225 microseconds, the receiver will turn on at 0.1 a mile with its gain programmed to change at the rate of 70 db per decade of range until its limit of 50 db is reached at about 0.5 mile range. The gain will then stay constant until the end of the range sweep.

2.3.4 DATA RECORDING

The images of the waves are recorded from the PPl scope via a 16mm Bolex H16M camera. A detailed description of a data system is given in the VTS Data Collection Trailer Documentation, U.S. Coast Guard Research and Development Center, Groton, Connecticut [7]. The camera recording system was designed for use on a Decca Marine Radar, but can very easily be modified as it was done by the Coastal Engineering Research Center, to use with the Raytheon radar system. Figure 6 shows a photo of the radar display with hood and camera attached as used by the Coast Guard program described in Reference 7.

The camera is mounted to the PPI scope via a hood. The camera shutter is synchronized to the radar sweep such that it is held open for one 360-degree antenna rotation every other rotation of the antenna. The data system includes additional information to be photographed via light emitting diodes (LED) mounted inside the radar hood. Figure 1 is a frame taken with this data system by the Coastal Engineering Research Center.

2.3.5 DATA REDUCTION

The data appears as a wave pattern on the photograph. The spacing and orientation of the wave pattern elements are the water wave components of the two directional slope

spectra. At present, there are two ways to reduce the data. One method uses a photo-optical data analyzer 16 mm projector to display the images at any rate including the ability to stop on any one. The CERC plans to use a simple device to measure the angular orientation and spacing of the principle wave components so projected.

Figure 7 shows a photo of the CREC device for measuring the principle wavelengths and their associated angular directions. The length scale arm is rotated to be normal to the wave direction and the distance between wave crests is recorded manually. The protractor is read and recorded for the angular direction of the wave component. If there are only a few wave patterns, this simple approach is adequate, but for more complex wave patterns and when very many wave images are involved an automated processing scheme is needed.

A more sophisticated method of data reduction uses a laser and lens arrangement to produce an optical two-directional spectra of the wave image. This technique is presently being done at the Naval Research Laboratory, Washington, D.C., the Coastal Engineering Research Center, Fort Belvoir, Virginia and the Applied Physics Laboratory. The production of wave spectra by this method is an art that requires a very good image and an experienced operator.

Laser processing of scene images to produce the two-dimensional spectrum will add the two important features of automation and the use of a digital computer to improve the quality of the directional spectrum.

Figure 2 shows a schematic of an optical bench. The laser light is passed through a pin hole and its image is focused on the Fourier transform plane by a single double spherical surfaced lens. If a scene film image of a single

sinusoidal component is placed after the lens, it will cause some of the laser light to be diffracted. The angle of diffraction is governed by the spatial wavelength of the scene and the laser wavelength as shown in Figure 3, where F is the distance from the scene image to Fourier transform image, X is the separation on the Fourier transform from the zero spatial frequency to the focus point of the diffraction ray, λ_L is the spatial wavelength of the laser light. Therefore, each spatial wavelength in the scene image will produce its corresponding and unique pair of spots on the Fourier transform image. The longer wavelength components in the scene image will be closer to the zero spatial frequency point and the shorter wavelength components will focus at the greater distance from the optical center line.

Another advantage of the optical bench processing of the scene images is that an image dissector can be used to scan the intensities at the Fourier transform plane and convert them to a digital format for processing in a digital computer. The computer does a smoothing operation that averages several transforms of the same scene taken at slightly different times. This has the effect of improving the contrast of the spectral components relative to the noise associated with the radar scattering at the water surface.

2.4 WAVE HEIGHT SENSOR

The imaging radar can provide information about the water wavelengths and direction, but not the significant wave height. Therefore, it is necessary to have another sensor on the ship to measure SWH. This can be accomplished with either a laser or radar ranging system to measure the waves near the ship.

The motions of the ship, i.e., pitch, roll and heave, that cause the distance from the sensor to the surface to change have to be measured in order to remove their effects on the result. For example, Figure 8 taken from Reference 8 illustrates how the distance to the surface R_o is altered by the ship's roll. J. L. Dalzell [10] gives a detailed analysis for removing the effects of the ship's motion from the radar range to arrive at measurements of the waves.

A comparison of the SWH derived from the shipboard ranging system with an airbrone laser profilometer was accomplished by flying the aircraft mounted laser near the ship for its data run. The shipboard radar took data for half an hour every hour. Figure 9 shows the SWH as measured by the shipboard radar and the airborne laser. The file numbers refer to shipboard data. The aircraft data was taken only at one location that was close to the second file of the shipborne data.

The significant wave height is an estimate of a statistical parameter of the waves. That means that successive estimates of SWH will vary due to the randomness of the wave height. The spread on the estimate of SWH and the fact that airplane data recording did not coincide exactly with the shipboard data recording account for the twenty percent difference in the estimates of SWH.

The candidate sensors to measure SWH are laser and radar ranging systems. The laser is a small, 3400 cm^3, self-contained system that uses a 10 cm objective lens. The radar system is also small, 2700 cm^3, but in addition, it needs two parabolic microwave antennas each about half a meter in diameter. The laser has a footprint of about 15 centimeters and the radar has a footprint of about 7 meters. The spatial resolution of either ranging system would be

adequate to complement the marine radar imaging system which has a spatial resolution of about ten meters. The relative cost of the two systems are quite different. A Collins Aircraft altimeter radar can be purchased for about $1500, and the laser will have to be special ordered and cost about $25,000 for the first unit and about $10,000 for additional units of the same design. There will be costs added to the radar to cover the purchase of the parabolic antennas, modifications to the radar and to include ship's motion sensors. The laser will cost more to purchase, but it will give better resolution in range, about 15 cm compared to 30 cm, and spot size about 15 cm compared to 7 meters.

2.4.1 LASER RANGING SYSTEM SPECIFICATIONS

Transmitter

Peak Power	15 Watts
Wavelength	900 Nanometers
Pulse Rate	60 Hz
Pulse Width	20 Nanoseconds
Objective Lens	10 CM Diameter
Beam Width	5 Milliradians
Physical Size	22.5 CM x 15 CM x 15 CM
Spot Size	30 CM

2.4.2 DESCRIPTION OF THE COLLINS RADIO, CO.[9] RADAR ALTIMETER MODEL ALT-50

The system specifications for the radar system to measure wave height are in Table 2.

The 860F-2 Radio Altimeter is housed in a case that measures 3.5 inches (8.9 cm) high, 3.585 inches (9.1 cm) wide and 13.905 inches (35.3 cm) long. The unit weighs 5.2 pounds (2.34 kg).

TABLE 2

CHARACTERISTIC	SPECIFICATION
Transmitter Output	
Power	150 milliwatts
Center Frequency	4300 ± 15 MHz
Modulation	
Selectable Frequency	100 or 105 Hz
FM deviation Peak to Peak	
100 Hz modulation	98.4 MHz
105 Hz modulation	93.7 MHz
Type of Service	Continuous
Altitude Output	
Analog characteristics	
-20 to 500 feet	20 *millivolts per foot* (30 cm)
Analog Accuracy	+2 feet (60 cm) or ±2% whichever is greater
Analog Time Constant	0.09 ± 0.01 second
Environmental Specifications	
Operating temperature range	
860F-2 Radio Altimeter	-54 to 71°C
Relative Humidity	95%
Cooling	Convection
Vibration	Conforms to DO-138 Category JN
Shock	
operational	6g
crash safety	15g
Primary Power Requirements	+22 to +34 V dc, 17 watts

2.4.3 ANTENNAS

The radio altimeter needs two antennas different from the ones supplied by Collins Radio Co. for use as a wave height sensor. These are simple paraboloids half a meter in diameter that are mounted as high on the ship as possible. There is a deck mount, see Figure 10, at NRL which was constructed by NRL for the SL-7 program [11] that can be used to mount both the antennas and the radio altimeter on the vessels' deck. The beam width of the antenna is about 10 degrees. This gives a resolution spot of about 7 meters which is the same as the imaging radar. The antenna is tilted out about 45 degrees with respect to nadir.

2.4.4 DATA RECORDING

The signal is in the form of an analog voltage with a calibration scale of about 20 millivolts per foot (30 cm). This is recorded either with an audio tape recorder or it can be digitized and recorded on digital magnetic tape.

2.4.5 ACCELEROMETERS

It is necessary to also have a gyrostabilized vertical accelerometer to record the vertical movement of the antenna [10]. The variance of the wave elevations is the difference between the calculated variance of the radio altimeter range changes corrected for the variance of the displacement of the antenna.

3.0 CONCLUSIONS AND RECOMMENDATIONS

Since no wave measurement system can be obtained commercially at the present time to record the two-dimension water wave spectra from a moving vessel, this report concludes that two commercially available radars or a radar-laser combination be used together to produce the image of the wave pattern and the wave height. The wave images are needed to determine the wavelengths and their angular orientation relative to the vessel. The other radar provides the needed wave heights.

The suggested radar system that produces wave images can also be used as an aid to navigation by the vessel's crew. The images are recorded as photographs of the PPI display scope by a semi-automatic camera system.

The wave height radar or laser needs a vertical mounted gyrostabilized accelerometer to record the effects of the ship's motion. Two parabolic antennas for the radar option, about half a meter in diameter each should be mounted as high above the water as possible. The antenna beam width is about ten degrees. This gives a resolution spot of about 7 meters if the antennas are about fifteen meters above the mean water line.

The three steps recommended are:

1. Replace the present Marine radar system on the m/v Stewart J. Cort with a Raytheon Model 1020 with the modifications and data recording features included in this report.
2. Mount a Collins Radio Co. radio altimeter or a laser ranging system high above the water line looking down and out from the vessel at about a forty-five degree angle.
3. Establish a six-month data recording and data reduction study to perfect the data analysis techniques.

The estimates costs of these recommendations are:

1. $15,000 to install marine radar system
   $ 5,000 for semi-automatic Camera recorder
   $ 2,000 for data display and analysis equipment

2. $1,500 for the Collins Radio Altimeter
   $ 500 for the parabolic antennas
   $10,000 for the data recording system

2-A. $25,000 for laser wave height sensor
   $10,000 for data recording system

3. $25,000 6-month data recording and analysis.

The pitch, roll and heave of the ship will all directly affect the radar measurement of distance to the surface. These changes in distance due to ship's motion need to be measured and removed from the distance indicated by the radar measurements to arrive at a correct estimate of water wave elevation.

The most desirable solution would be to mount the radar antenna on a stable platform that remained level. The stable platform would also serve as the location of a vertical accelerometer to record the vertical excursions of the radar.

Since the Great Lake's ore vessels are so large and block-like, it is assumed that the pitch motion is very small. Therefore, it is possible to use a platform that is stabilized in the roll axis only. This will simplify the installation.

REFERENCES

1. M. H. Tucker, "A Shipborne Wave Recorder", Spring meeting of the Institution of Naval Architects, March, 1956.

2. Henry Carleton, "Wave Height Indicators", Technical Report NMRC-KP-123A, prepared for the National Maritime Research Center, Kingspoint, New York, 1974.

3. Lee Harris and Mike Mattie, Coastal Research Engineering Center, Fort Belvoir, Virginia. Personnel communications.

4. Denzil Stilwell, Jr., "Directional Energy Spectra of the Sea from Photographs", Journal of Geophysical Research, Vol. 74, No. 8, April 15, 1969.

5. Denzil Stilwell, Jr. and R. O. Pilon, "Directional Spectra of Surface Waves from Photographs", Journal of Geophysical Research, Vol. 79, No. 9, March 20, 1974.

6. Instruction Manual, Mariners Pathfinder Radar, Models 1020/4XR, 1020/6XR, 1020/9XR, Raytheon Marine Co., Manchester, New Hampshire.

7. J. J. Cherney III, "VTS Data Collection Trailer Documentation", U.S. Coast Guard Research and Development Center, Groton, Connecticut, May, 1976.

8. Davidson T. Chen, B. S. Yaplee, D. L. Hammond, Paul Bey, "Wave Measurement in the Open Ocean", Proceedings, 15th International Coastal Engineering Conference, Pgs. 72-91, July, 1976.

9. Instruction Book Radio Altimeter System ALT-50, Collins Radio Co., Cedar Rapid, Iowa.

10. J. E. Dalzell, "Correlation and Verification of Wavemeter Data from the SL-7", Report SIT-DL-77-1944, Davidson Laboratory, Stevens Institute of Technology, Hoboken, New Jersey, April, 1977.

11. W. J. Siekierka, R. A. Johnson, CDR C. S. Loosmore, USCG, "SL-7 Instrumentation Program Background and Research Plan", SS-257 (SL-7-5) Ship Structure Committee, 1976.

ACKNOWLEDGMENTS

The author takes full responsibility for any flaws in the report, but at the same time would like to mention some others whose help along the way was greatly appreciated.

LTJG Steve Judson, U. S. Coast Guard, supplied copies of reports of related work, arranged meeting with others who are working on similar problems and most of all he engaged in many helpful discussions with the author.

Dr. Lee Harris and Mike Mattie of CREC, Ft. Belvoir, Virginia, were most generous in sharing the results of their marine radar images of coastal waves.

John Paradis of the Surface Effects Ship Research Center, Patuxent River, Maryland, supplied the information on the Collins radar altimeter.

Fred Browning, William Veiga and Rick Wetmore of Raytheon supplied the information about the Model 1020 marine radar system.

Al Wolfe of Raman, Cleveland, Ohio, supplied the information about the installation of marine radars on the Great Lakes vessels.

Benjamin Yaplee, Allan Shapiro and Lawrence Choy made many helpful suggestions on the organization of the report.

Marie Spangler and Marlene Zulueta maintained a friendly attitude while giving editorial guidance and typing the report again and again.

Roger Pilon did the optical processing and interpretation of the radar wave image used in the report. He also supplied the information about the optical processor.

Joe Jepsky of Associated Controls and Communication, Inc., Lynn, Massachusetts supplied the information about the laser ranging system.

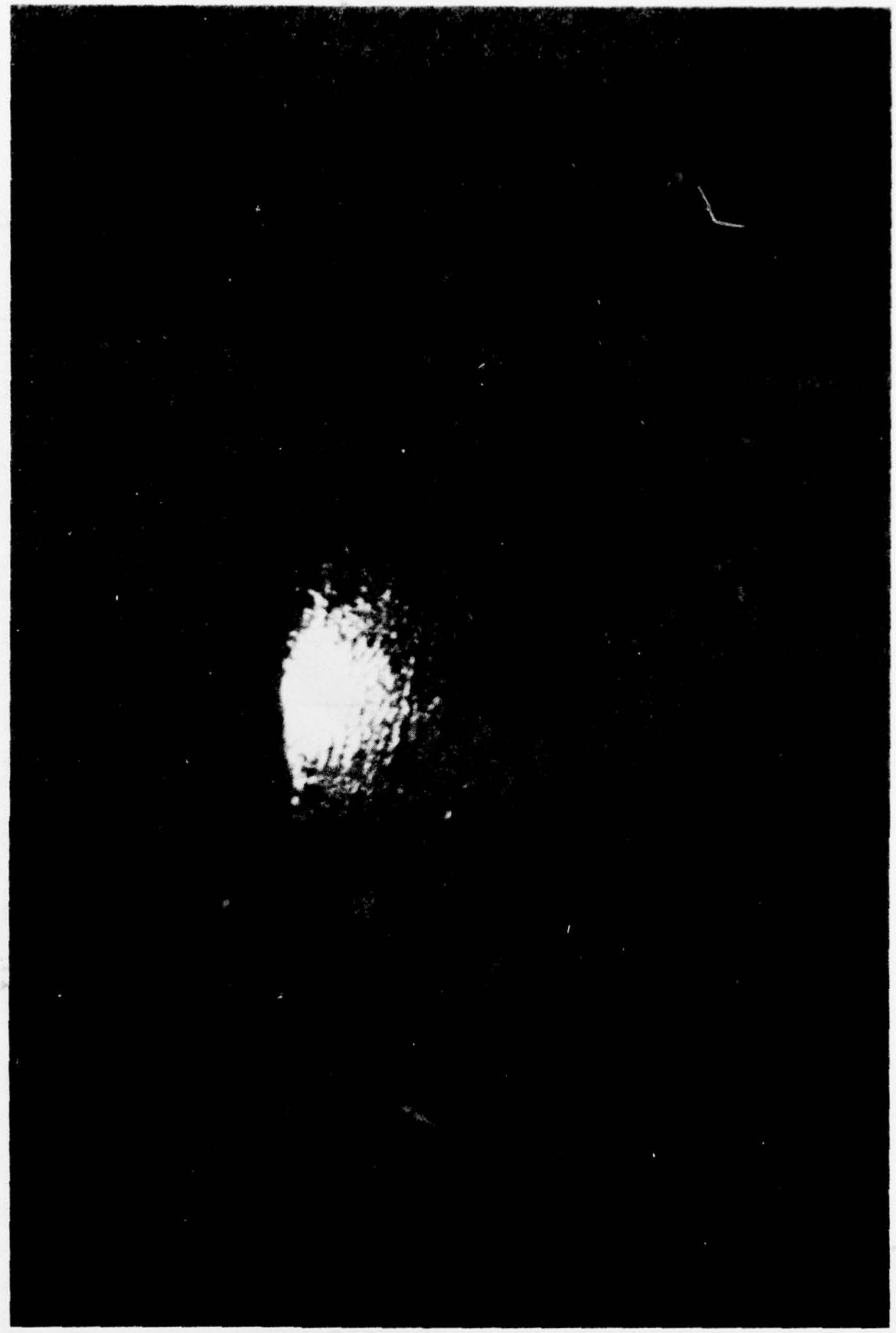


FIGURE 1 – PHOTOGRAPH OF A RADAR IMAGE OF WATER WAVES AT A BEACH. THE FULL SCALE RANGE FOR THE RADAR IS 3/4 MILE.

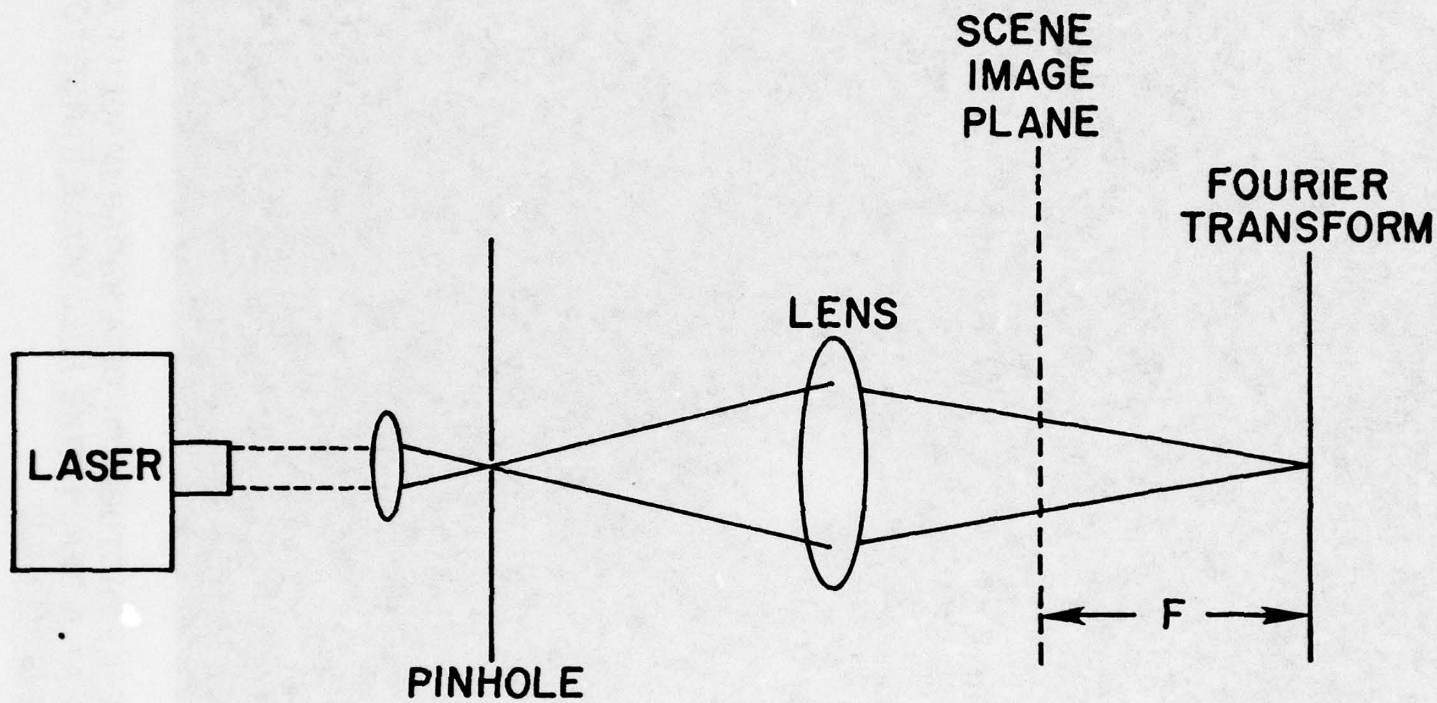
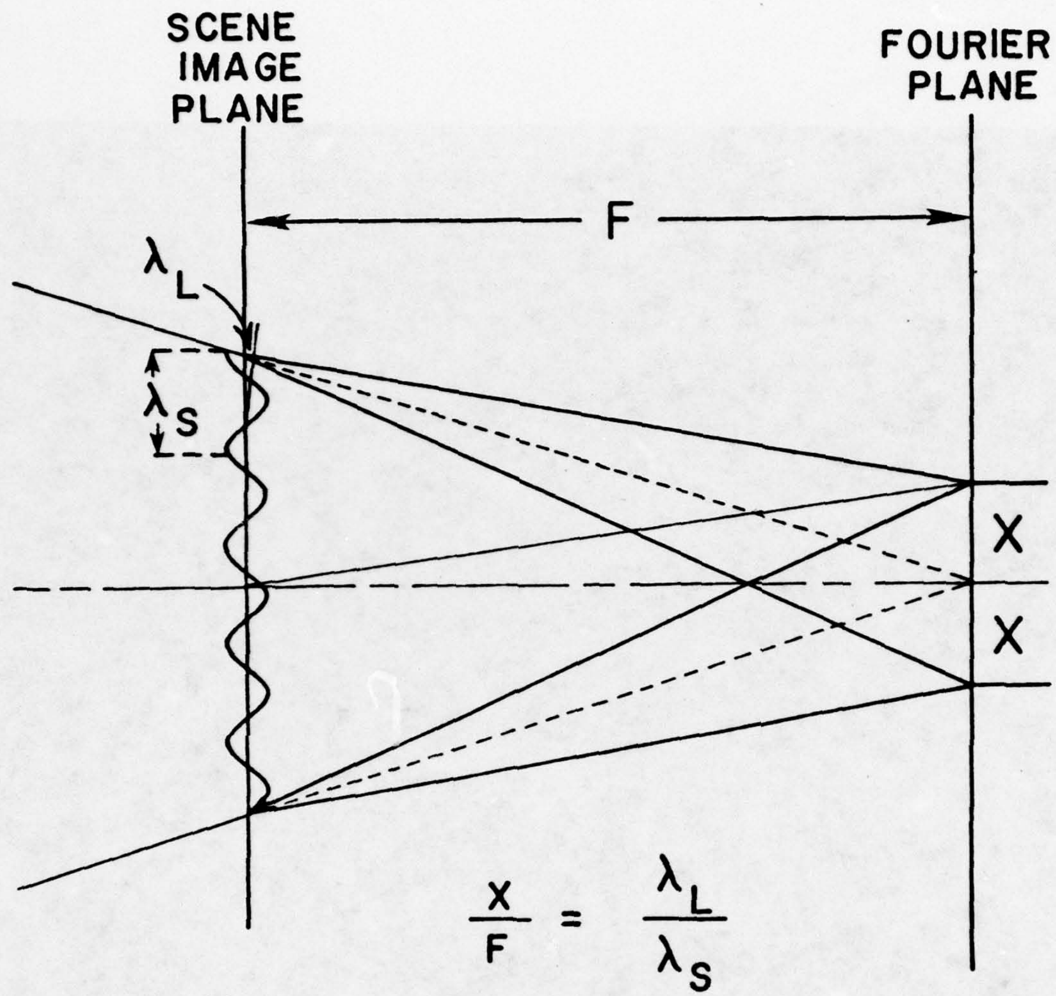


FIGURE 2 – SCHEMATIC DIAGRAM OF AN OPTICAL PROCESSOR.



$$\frac{X}{F} = \frac{\lambda_L}{\lambda_S}$$

FIGURE 3 – THE RELATION BETWEEN A SPATIAL FREQUENCY COMPONENT IN THE SCENE IMAGE AND ITS LOCATION IN THE FOURIER TRANSFORM PLANE.

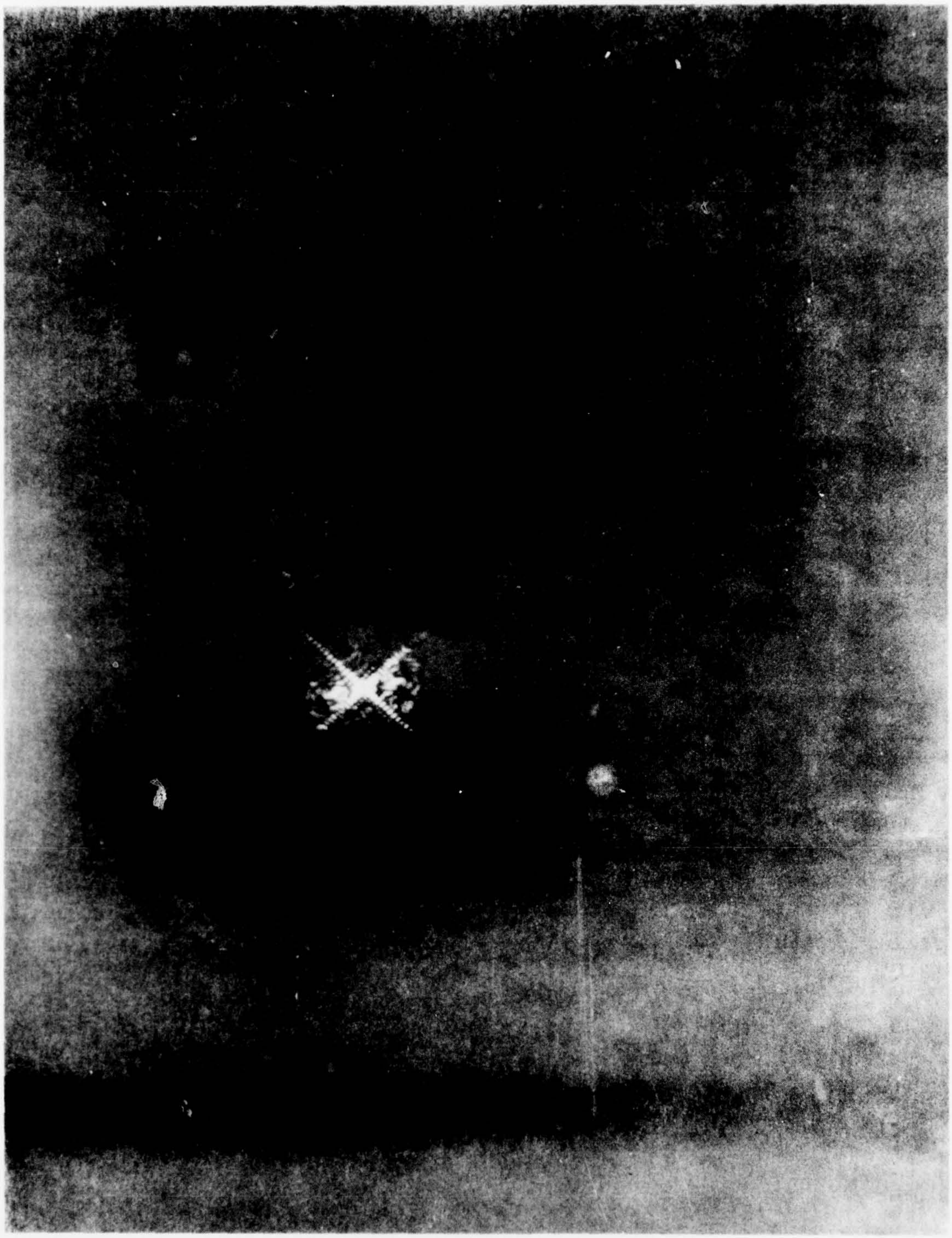


FIGURE 4 – AN EXAMPLE OF A TWO-DIMENSIONAL SPECTRUM.

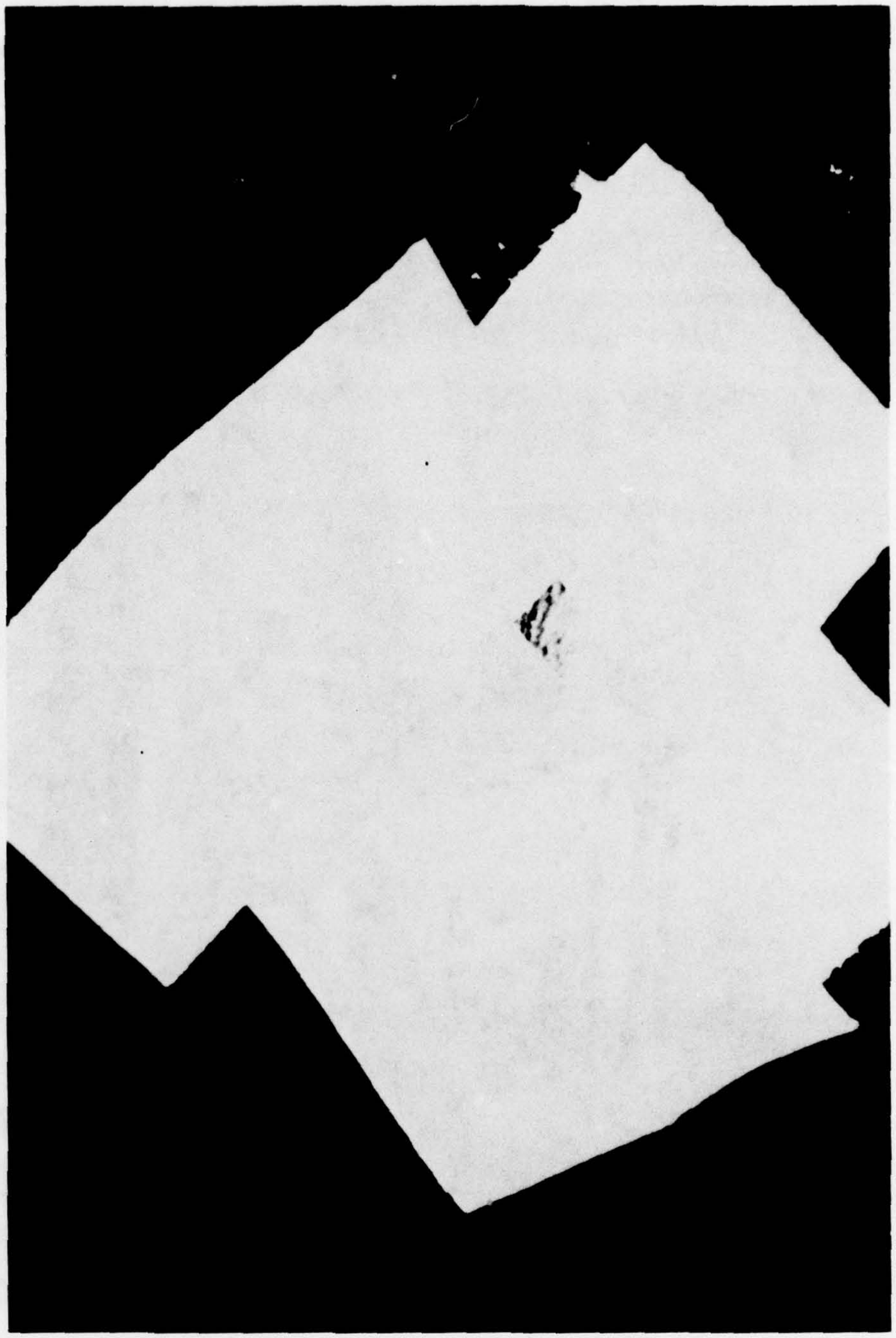


FIGURE 5 – A RADAR WAVE IMAGE WITH A MASK APPLIED TO SELECT A REGION TO BE PROCESSED.

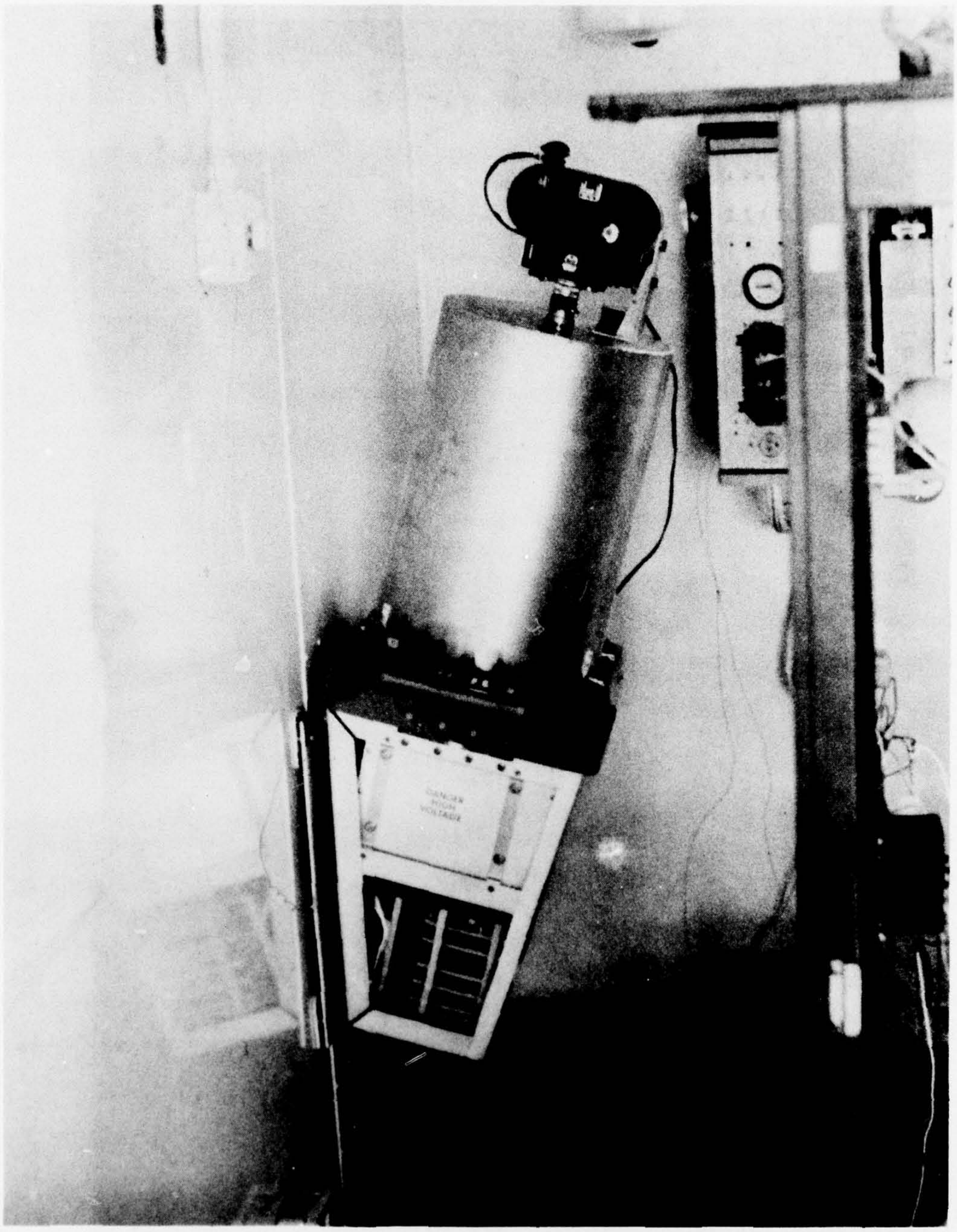


FIGURE 6 – PHOTOGRAPH OF A MARINE RADAR DISPLAY WITH THE HOOD AND RECORDING CAMERA ATTACHED.

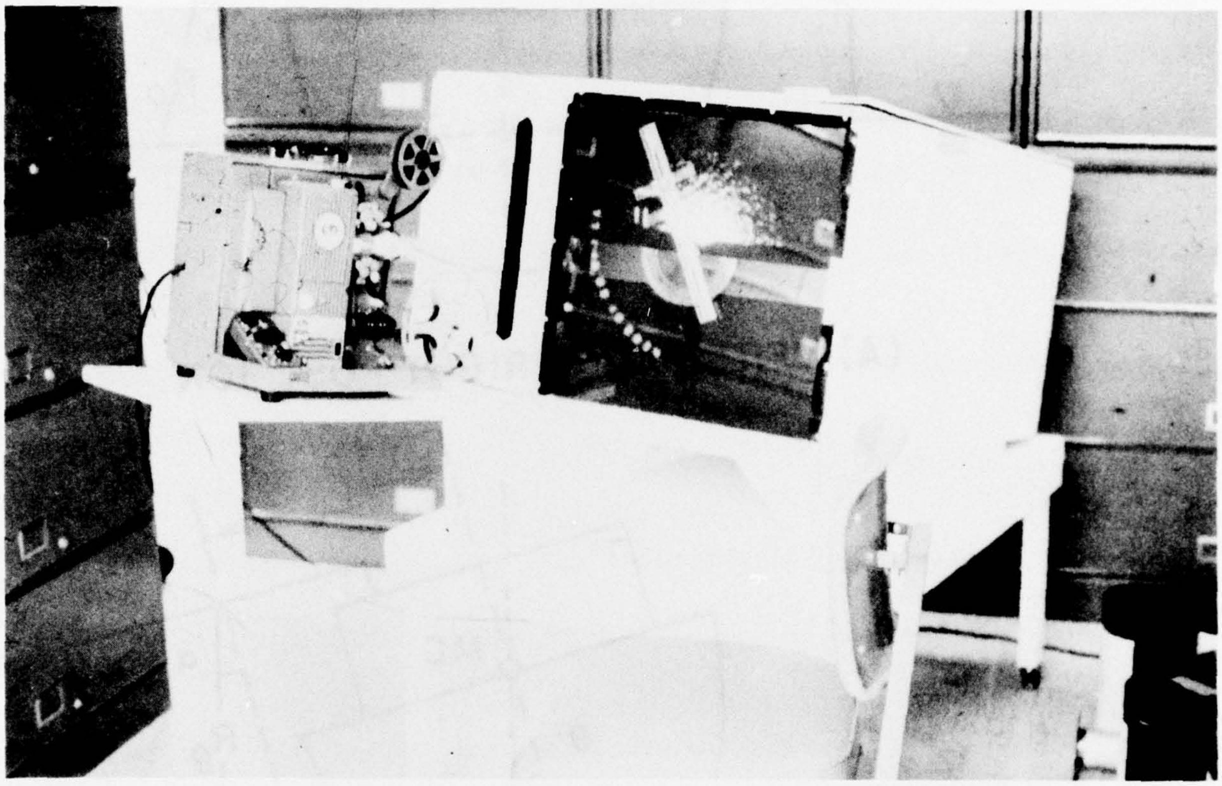


FIGURE 7 – THE PROJECTOR SYSTEM AND WAVE MEASUREMENT DEVICE USED BY THE COASTAL RESEARCH ENGINEERING CENTER.

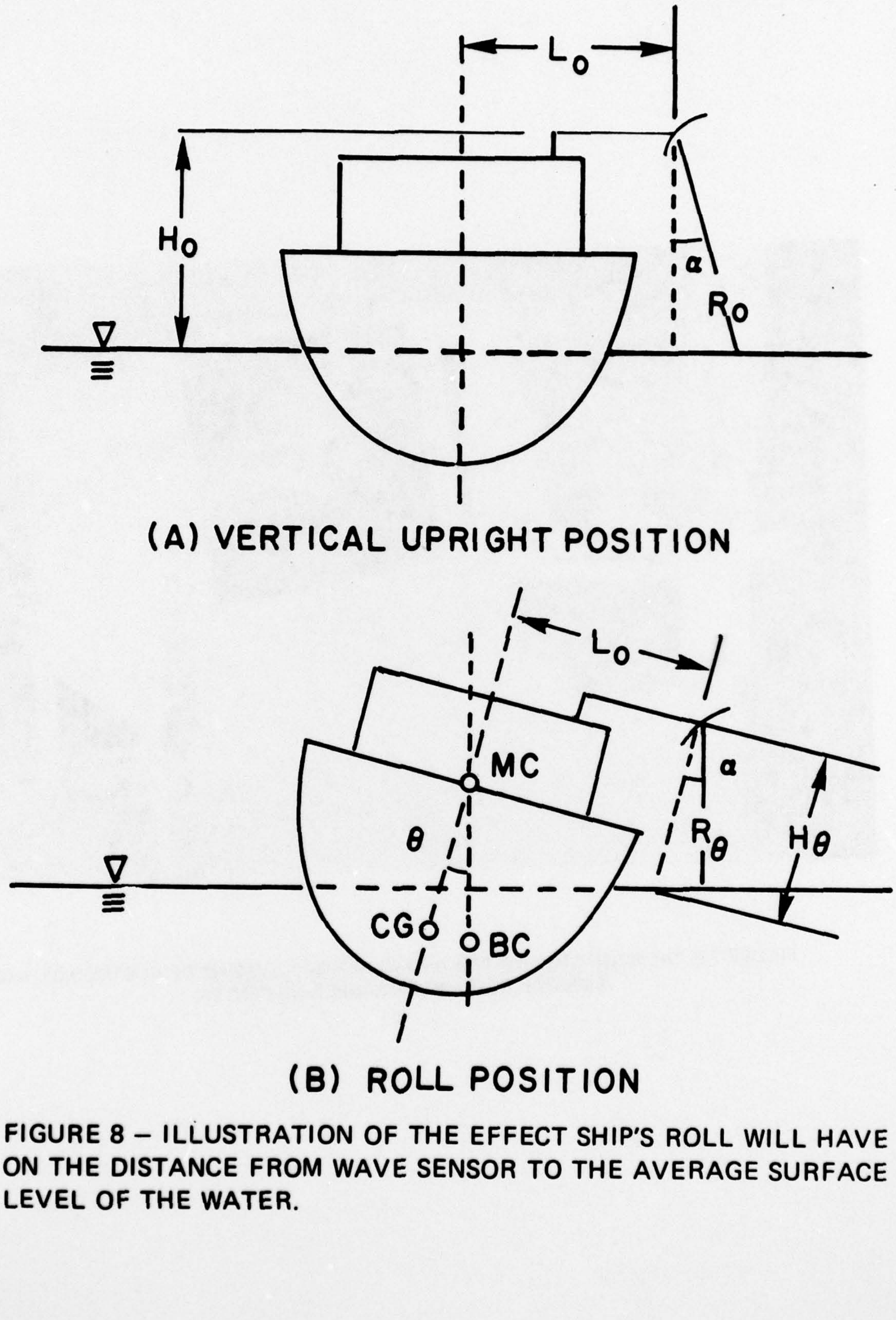


FIGURE 8 – ILLUSTRATION OF THE EFFECT SHIP'S ROLL WILL HAVE ON THE DISTANCE FROM WAVE SENSOR TO THE AVERAGE SURFACE LEVEL OF THE WATER.

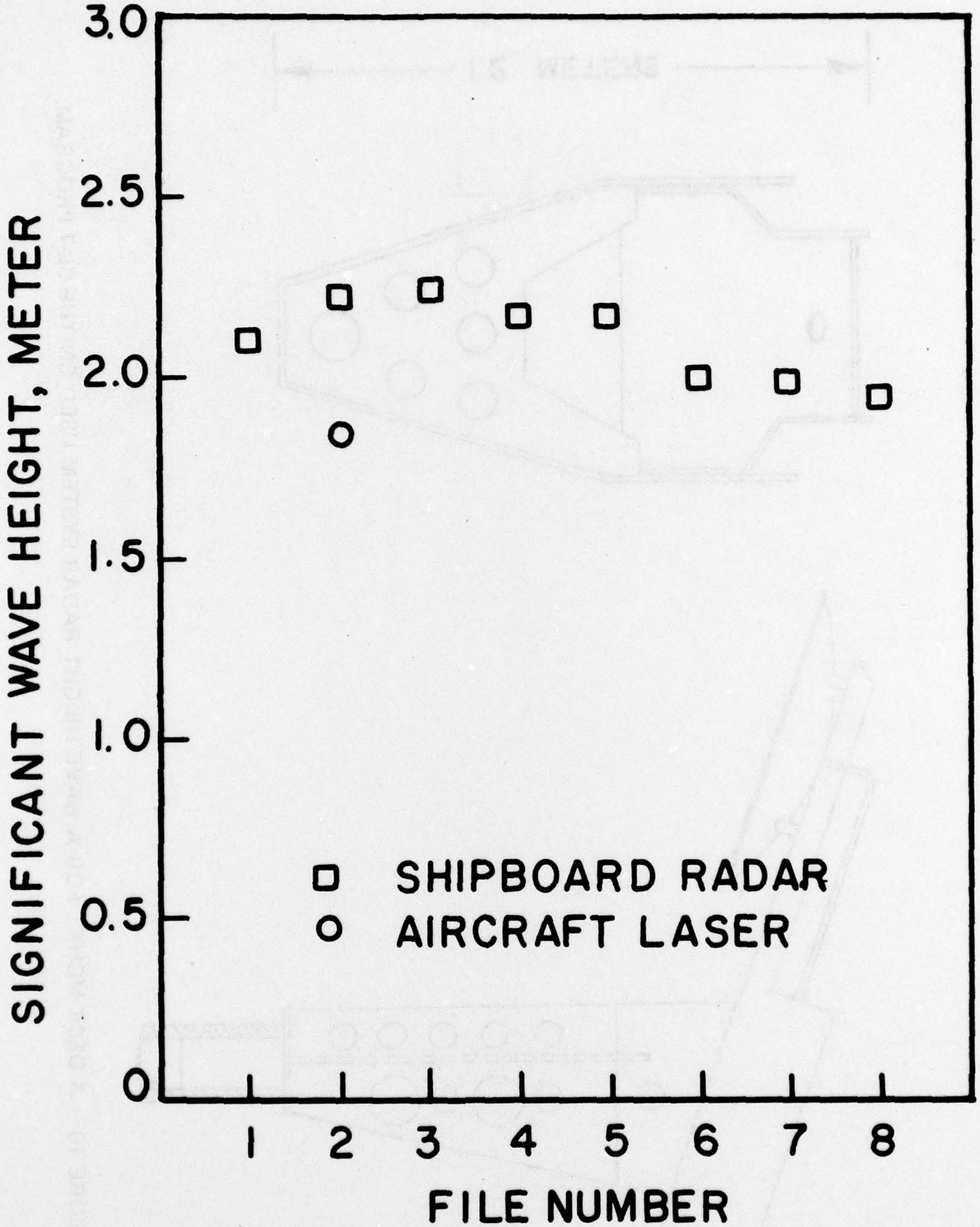


FIGURE 9 – A PLOT OF SIGNIFICANT WAVE HEIGHT DATA TO COMPARE A SHIPBORNE MEASUREMENT WITH AN AIRBORNE MEASUREMENT.

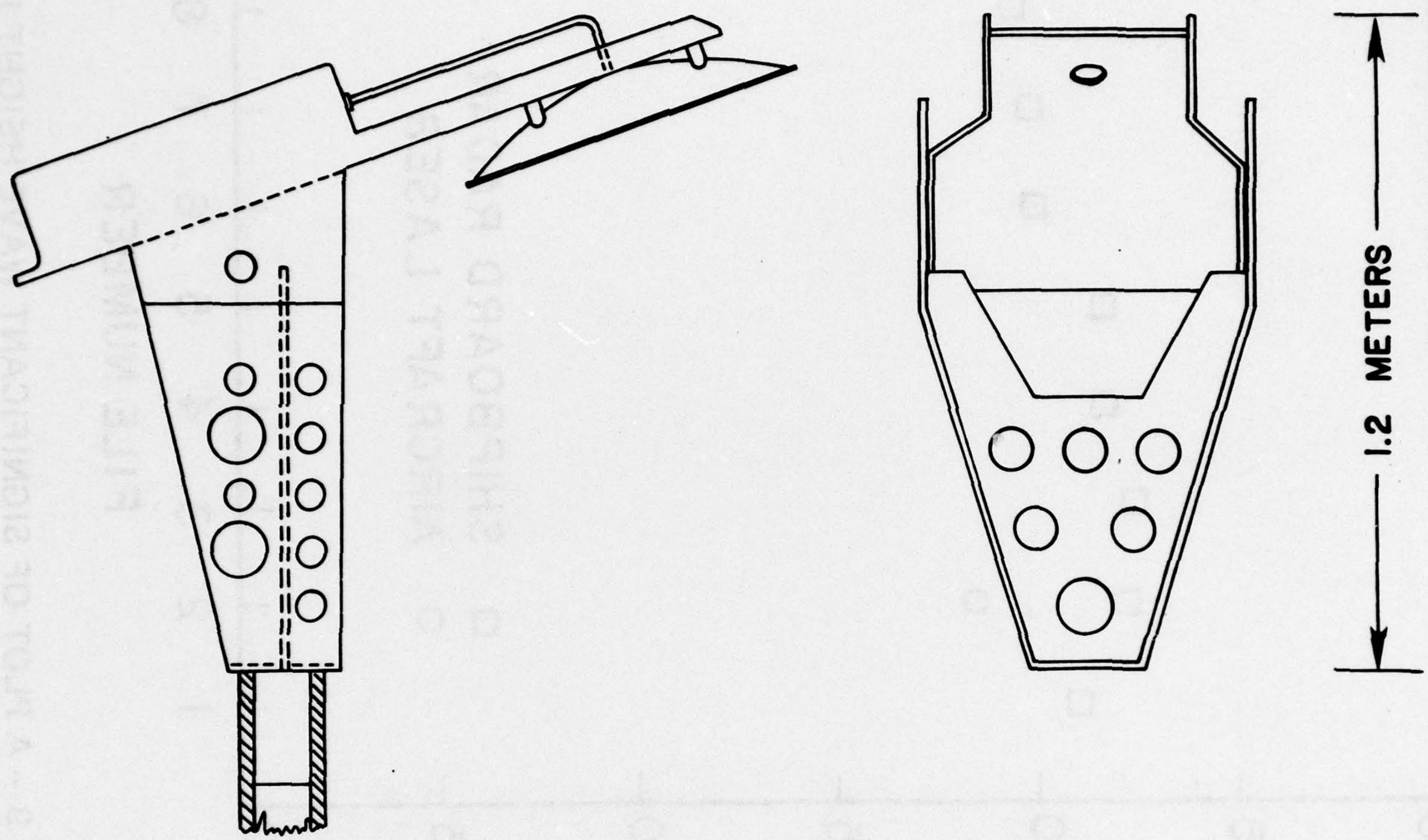


FIGURE 10 – A DECK MOUNT FOR A WAVE HEIGHT RADAR SYSTEM USED ON THE SL-7 PROGRAM.